Post-Larval Lobster (*Homarus americanus*) Distributions in Penobscot Bay in Relation to Hydrography, Circulation and Remote Sensing Information

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"Applications of Remote Sensing and Geographical Information Systems for Marine Resources Management in Penobscot Bay, Maine"

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INTRODUCTION

Our objectives in 1999 were to: (1) sample the distribution and abundance of planktonic lobsters in Penobscot Bay, with an emphasis on the postlarval stage; (2) collect data on sea surface temperature (SST) and meteorology (wind, air temperature, cloud cover) from each station; and (3) collect as many CTD profiles as time would permit. The postlarva is the final planktonic stage and is sometimes referred to as a Stage IV lobster because it is the fourth developmental stage after hatching (the first three stages are larvae). The postlarva resembles a benthic stage lobster and is morphologically very different from the larval stages.

Objective 1 was designed to test the hypothesis that postlarvae enter Penobscot Bay primarily via the western channel (west of Vinalhaven Island), resulting in greater recruitment near the mouth of the bay and in western portions compared to the northern and eastern bay. Inherent in this hypothesis is the assumption that most postlarvae come from coastal waters. The hypothesis originates from findings in 1998 which suggest that the upper layer of the bay circulates in this clockwise manner during summer months, and other findings that indicate higher lobster production and recruitment in the western channel. Observed patterns of postlarval distribution will be qualitatively and quantitatively compared with physical oceanographic measurements and benthic settlement patterns to evaulate sources of postlarvae, mechanisms of transport and delivery, and consequences for recruitment. SST, meteorological data and CTD data (Objectives 2 & 3) will contribute to the collaborative study and modeling of circulation in the bay and provide data for comparing property distributions and inferred transports with remote sensing information.

We established a grid of sampling stations around Vinalhaven and North Haven islands that provided for an unbiased assessment of larval and postlarval distributions. Thirty-nine standard stations were distributed around the central archipelago (Fig. 1). Nine additional offshore stations were sampled once during the season. Sampling was done with a neuston sampler 1 m wide x 0.5 m submerged portion which was towed at approximately 2 nm/h from a side boom. A mechanical flowmeter in the mouth of the net measured the distance towed, which was used to convert the catch rate to a standard area of 1000 m^2. SST was measured using a bucket sample at the beginning and near the end of each tow. Wind speed and direction, air temperature, cloud cover, and wave and swell height and direction were recorded at each tow. CTD profiles were collected from surface to near bottom using an internally recording Seabird Electronics SBE19 lowered and raised by hand over a davit and pulley. Net catches were sorted on deck. Larvae and postlarvae were removed and counted, placed in 4-oz jars of chilled seawater, and stored on ice and in the dark for later examination. Larval identifications and counts were later verified (sometimes the initial identification was difficult due to sea state) and the postlarvae were examined under a microscope to assess molt-cycle stage. Molt stage can be used in conjunction with SST to assign an approximate age to the organism.

The work was conducted by myself, Nick Wolff, Ford Dye (all of Bigelow Laboratory) and summer undergraduate student intern Katie Graham Dye (Allegheny College). A second intern, Laura DeVincentis (Bowdoin College), conducted a study of ten years of wind data at Isles of Shoals, Portland buoy, Matinicus Island, Mount Desert Rock and the Gulf of Maine buoy. We used the University of Maine's R/V Nucella, a small (29' LOA) but fast vessel (up to 30 nm/h) which enabled us to cover the large distances involved. It was ably captained by John Higgins, of Stonington, who never concerned himself with the often long days. This combination of vessel and captain enabled considerably more sampling than we had anticipated. The over- night was usually spent encamped on Hurricane Island, courtesy of the island's owner and the Hurricane Island Outward Bound School, whom we thank.

RESULTS

We sampled two days per week from June 24 to September 2 for a total of 24 sampling days over 12 weeks. We lost one day (not counted above) due to a broken net frame and part of another day due to weather and mechanical problems with the engines. With only a few exceptions, all 39 standard stations were sampled each week.. The speed that we were able to make between stations most of the time enabled us to get CTD profiles every time we obtained biological samples, exceeding our initial expectations. In some cases we obtained CTD profiles when we did not have time for, or working conditions did not permit, neuston tows. In total, we collected 391 neuston samples and 403 CTD casts.

Stage I Larvae

One hundred and forty two of the tows (36%) contained either larvae or postlarvae. Nearly all of the larvae were first stagers (SI), which was expected because this stage is more positively phototaxic than the next two (SII and SIII, of which we caught only a few). Neuston tows are not quantitative for SI, however, because this stage is not concentrated in the neuston layer (top 0.5 m in our sampling protocol) and the proportion in the neuston is variable due to diel and weather-related changes in light level and probably other factors. Thus, SI distributions in the neuston layer are indicative of the presence of this stage, but the data cannot be used to calculate absolute abundance. We looked for time-of-day biases in our catches. We would expect to catch more SI larvae early in the morning and late in the afternoon or early evening due to decreased light levels in the water column: did we tend to sample the same stations at these times of day?. In fact, a plot of time-of-day vs. catch rates showed only weak diel patterns of abundance which did not subvert the nature of the spatial patterns we found. Our data show the highest numbers of SI larvae consistently south of Vinalhaven Island and in the western bay, but the larvae were present in all transects except Transect F (Fig. 2). Correcting for water temperatures and the rate of larval development, we estimate that most of the SI we collected were no more than 7 days old (after hatching). Since we do not know the ages of individuals better than this, we must assume that the sampled distributions of SI larvae reflect a combination of influences, including the distribution of females hatching their eggs and the effect of residual transport on the larvae. Despite this uncertainty in where the larvae came from or how far they had been moved, the patterns are striking, and we will be giving them further consideration in conjunction with the physical oceanography, remote sensing data and egg-bearing female distributions.

Lobster Postlarvae

We caught only 31 lobster postlarvae in 1999. The largest number caught in a single tow was 4 (south of Vinalhaven on August 17; Fig. 3). According to prior experience in the Boothbay region (1989-1995), this number should have been encountered frequently. When we sampled “offshore” to Matinicus Rock on August 24 (see Fig. 1 for locations), we caught postlarvae more consistently (4 out of 8 stations sampled), but not in higher numbers. We are certain that the spatial and temporal coverage we gave Penobscot Bay in 1999 did not miss significant influxes of postlarvae. Rather, we believe that postlarvae simply were in low abundance in the bay this year. In early August, graduate student Eric Annis (U. Maine) collected neuston samples along transects orthogonal to the coastline off of Penobscot Bay. He found good numbers of postlarvae offshore (data have not yet been normalized to a standard area, so are qualitative), but none near the mouth of the Bay. Why the low numbers inshore? This is an important question that relates to sources and delivery mechanisms of postlarvae to Penobscot Bay, and it will receive further attention as the joint studies of the Pen Bay collaborative advance.

Because so few postlarvae were caught in the study area in 1999, estimates of average PL density cannot be calculated with much confidence, except for Transect C south of Vinalhaven (Fig. 3 and Table 1). For all other transects, we obtained zeroes at most stations most of the time. We cannot know whether these were "true" zeroes (*i.e.*, postlarvae were not present at all) or simply low values below the level of detection using our methods (*i.e.*, fewer than 1 individual per unit of towed area). This distinction is not usually important. If we had had high abundances at some stations or along some transects and not others, then we would have had a pattern to interpret. In the case we have this year, we cannot reliably distinguish between transects where a few postlarvae were found and those where none were found. That is, the biological signal was not strong enough this year to test the hypothesis we set out to evaluate. It is nonetheless useful to derive some measure of postlarval abundance for comparison with other years and areas, and for comparison with settlement data from R. Steneck’s work, so we proceeded as follows. We established the lower level of detection for each transect based on the average surface area sampled each week. For these calculations we assumed a uniform distribution of postlarvae. (Other statistical distributions such as a Poisson distribution may be more appropriate, but this cannot be judged from this year's data). If we caught postlarvae, then those catches were used to estimate abundance; if we did not, then we report that the abundance was below the level of detection. We estimate that the season began the day that the first postlarva was caught (July 13) and we calculate the abundance through the last day of sampling, which was September 2. The postlarval season probably extended beyond this date, but we had not planned for late season sampling because it usually adds little to the annual production. In this case there were other factors which sealed this decision: (1) boat time was unavailable for the next 15 days; and (2) a hurricane passed offshore in mid-September which would have dominated any changes in data. There seemed little opportunity for adding to what we already had.

Table 1 shows that the total number of PL-days was highest along transect C but less than 36.8/1000 m^2 along all transects in Penobscot Bay in 1999. This is lower than all prior observations we have made. We meausured an average of about 200 PL-d/1000 m^2 in the Boothbay Harbor region and off Seabrook, NH in a previous study covering seven years (1989-1995: Incze et al., in press). The lowest prior observed value in the Boothbay region was 123 /1000 m^2 in 1993. The four years since that published study have yielded low values off Seabrook, but not quite as low as those found this year in Penobscot Bay. Seabrook values were: in 1996, 121 PL-d; 1997, 64 PL-d; 1998, 47 PL-d; and 1999, 87 PL-d /1000 m^2.

Wind Data from Gulf of Maine Stations

We downloaded 10 years of wind data (hourly mean speed and direction) for June, July and August, 1988-1998 from the NOAA on-line database. Data were downloaded for the Isles of Shoals, Portland buoy, Matinicus Rock, Mount Desert Rock and the Gulf of Maine buoy. For Matinicus (off the mouth of Penobscot Bay), we later downloaded the data through August 1999. In addition, we obtained data from a land station on Newcastle Neck, New Hampshire, almost directly onshore from the Isles of Shoals. The data have been cleaned up for missing and suspect values and converted to component values for statistical analysis based on geographical components (N-S) and rotated axes oriented to the local shoreline. The current database contains more than 111,000 records. We have used the database to examine average wind directions and strengths at the various stations, interannual variations in component winds during summer months (when lobster larvae and postlarvae are present), daily patterns of rotation due to local sea breezeeffects, the presence of nocturnal land breezes (common only at IOS), orientation of prevailing wind directions to the neighboring coastline, coherence of patterns along the coast, and across-shelf gradients in velocity (IOS-Newcastle). We are in the process of examining patterns between wind strength/direction and events at Portland and recruitment in the Boothbay region (with R. Wahle), and winds at IOS and postlarval abundance at Seabrook, NH. For both sites we have a 10-year record of either lobster settlement or postlarvae. This is work in progress relative to recruitment processes and will be reported at a later date. Of immediate relevance to

Penobscot Bay is the Matinicus data set. In particular, we wish to know how much the various years differ, in what ways, and do the data show anything unusual about this year (1999) when we found so few postlarvae. A preliminary examination of the data do not immediately suggest an explanation for the low postlarval numbers found this year, but we will look at these data more closely in the coming year.

SST and CTD Data

Sea surface temperatures (bucket samples) and profiles of salinity and temperature (CTD) collected every week from nine transects (Fig. 1) provide insights into circulation patterns and ground truth for satellite observations. Properties show gradients from north (upper bay) to south (lower bay), but also readily distinguish between western and eastern channels, which we discuss below. These patterns corroborate those shown by previous mooring records, but now add spatial resolution. Most transects show across-channel gradients in T and S which warrant further analysis. Here, we provide an overview based on transect averages of SST and salinity. Salinities are from 2 m depth because data from this depth were available from all the CTD casts. We use the surface temperatures rather than data from 2 m because these values are more useful for comparisons with satellite data and larval abundance. Temperatures at 2 m were cooler than at the surface but show similar spatial and temporal patterns.

SSTs on transects A, G, H, and I were the warmest on average and group closely together; transects B, C, F and E are the coolest and also group together. Values from D and D-2 form a third distinctive group (Fig. 5). The divergence of values at D and D-2 from the transects on either side of them (E and C) requires closer scrutiny. In particular, we will look at the relatively cooler temperatures during the warmest period of the summer (see DOY 200-215) to see if they resulted from a bias in sampling times, either due to time of day effects (for instance, wind speed) or tidal stage. With respect to the latter, we are working on a tidal displacement correction for all samples to provide a synoptic plot of values adjusted to a constant tidal phase. This cannot be done with profile data, but can be done with surface values, including temperature and larval abundance.

Near-surface salinities (at 2 m) are systematically lowest at H and I , then G and A (Fig. 6). Temporal differences, and some of the spatial ones (among transects) are influenced by the stage of tide when the transects were sampled, and this will be analyzed with synoptic corrections as mentioned above. A gradual seasonal increase in salinity of about 0.5 ppt is best seen at the outermost transects: C, B and D. The decrease in salinity on DOY 237 at E, F and G is the result of an ebbing tide. Note that the salnity is lower at G than at F despite the passage of little time between the two transects. On transect E on that same day, most of the low salinity was at the station closest to North Haven; the rest of transect E resembles F (not shown here). Transect D did not show much freshwater influence, but it was sampled earlier in the ebb cycle. Transects F and E generally were 1-2 ☜C cooler in the upper layer than A, G, H or I. This may be the result of vertical mixing at F and elsewhere (but probably not at E itself, which is deep and remains stratified). Despite its being relatively shallow, transect G was stratified in all of our samplings, suggesting less turbulent mixing and lower average velocities than some other areas. Transect F, in contrast, usually was poorly stratified. These findings suggest that much of the tidal flow in the eastern bay proceeds through transect F. The question of what happens at G is critical to the larval transport question, and suggests that some tidal and residual transport calculations should be made there next year.

Salinity and temperature data show a close affinity between Transect C and transects B and D in the outer bay. This indicates strong coastal water influence on both transects, probably through tidal excursions and mixing. CTD profiles on transect C show that the warmest surface waters typically occur in the northern half, toward Vinalhaven. This also is where most of the larvae and postlarvae were collected. One possible explanation is surface convergence along the south shore of Vinalhaven Island, possibly forced by the prevailing southerly winds. We will be analyzing these data in concert with wind records from Matinicus.

DATA PRODUCTS

Along with this written report we are submitting:

(1) an electronic version of the report with figures for use on the project web site;

(2) a single digital data file in GIS format of the neuston collections, including meteorological observations;

(3) a tarred file of all of the CTD data in GIS format; and

(4) a metadata file describing data collection, processing methods and file stuctures for the data sets.

Table 1. Summary of postlarval catches and estimated abundances at the standard sampling stations. The number of positive weeks refers to the number of weeks in which at least one postlarva was found on the specified transect. "Total number caught" refers to the entire sampling season. "Average detection level" refers to the sampling sensitivity and is the average calculated abundance (No./1000 m^2) if one postlarva had been caught per transect. "Average density" is the seasonal average for the time period July 13 to September 2 (see text for explanation). Where no postlarvae were caught all season, the average density is given as "< level of detection" (*e.g.*, transect D-2). Since all transects had zero catch levels (below detection) during some weeks, the average of all weeks is always "less than" some value. "PL-d" is the integration, over time, of the postlarval density on each transect. "Year" refers to the 1999 postlarval season, but technically is limited to the period July 13-September 2 (see text).

Transect	No. Weeks Sampled	No. Positive Weeks	Total Number Caught	Average Area Sampled m^2 / week	Average Detection Level Level (No./1000m^2)	Average Concentrations (No./1000m^2)	PL-d (No./1000 m^2/year)
A	8	1	1	4352	0.231	< 0.234	< 11.934
B	8	3	6	5096	0.197	< 0.299	< 15.249
C	8	5	14	3919	0.264	< 0.722	< 36.822
D	8	1	3	3432	0.293	< 0.396	< 20.196
D-2	7	0	0	1666	0.603	< 0.603	< 30.753
E	8	2	2	3594	0.279	< 0.285	< 14.535
F	6	0	0	1703	0.588	< 0.588	< 29.988
G	7	0	0	2186	0.472	< 0.472	< 24.072
H	7	0	0	3322	0.302	< 0.302	< 15.402
I	7	1	1	3732	0.272	< 0.277	< 14.127

Fig. 1. Standard sampling stations (closed circles) sampled once per week from June 24 to September 2, 1999. Transects are identified by letter and referenced in the text. Open triangles are extra stations sampled on August 24.

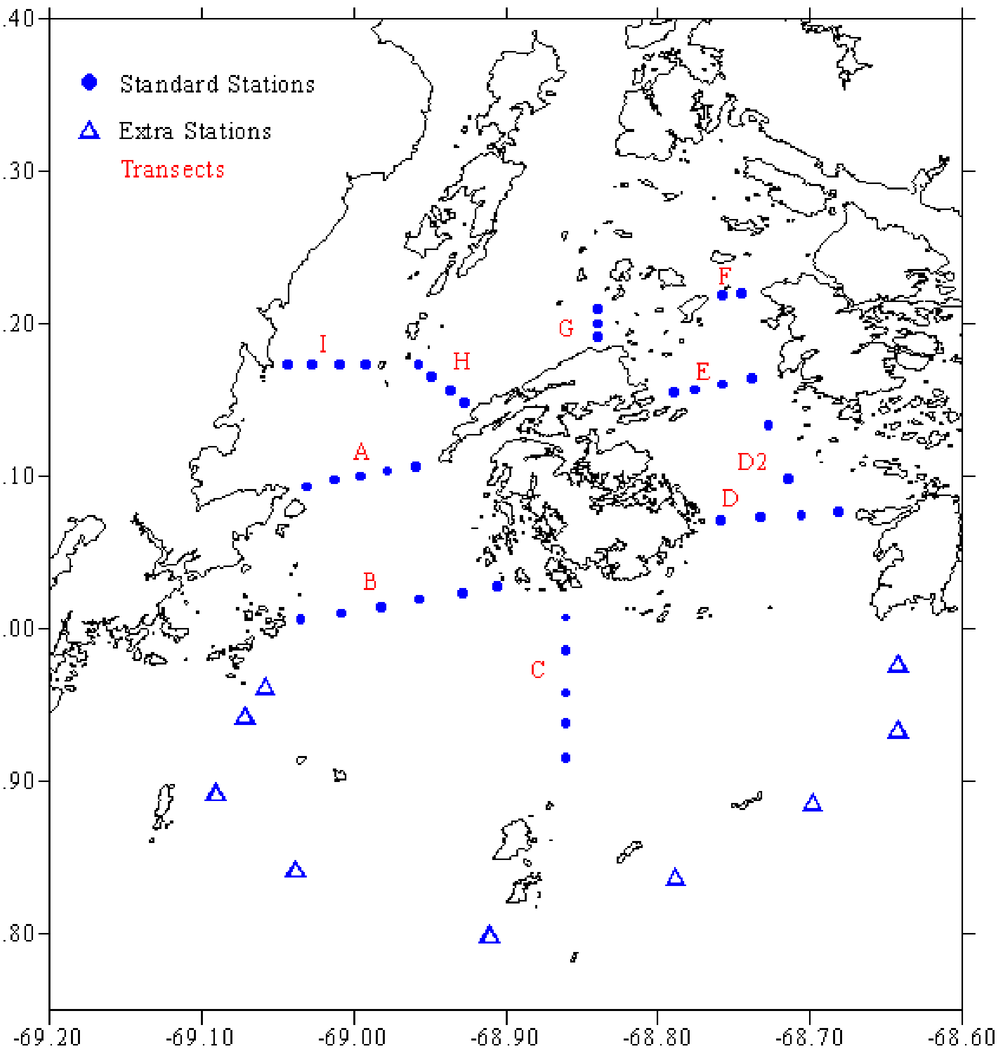

Fig. 2. Total number of Stage I lobster larvae collected at each sampling station during 1999. Stations from August 24 are not shown.

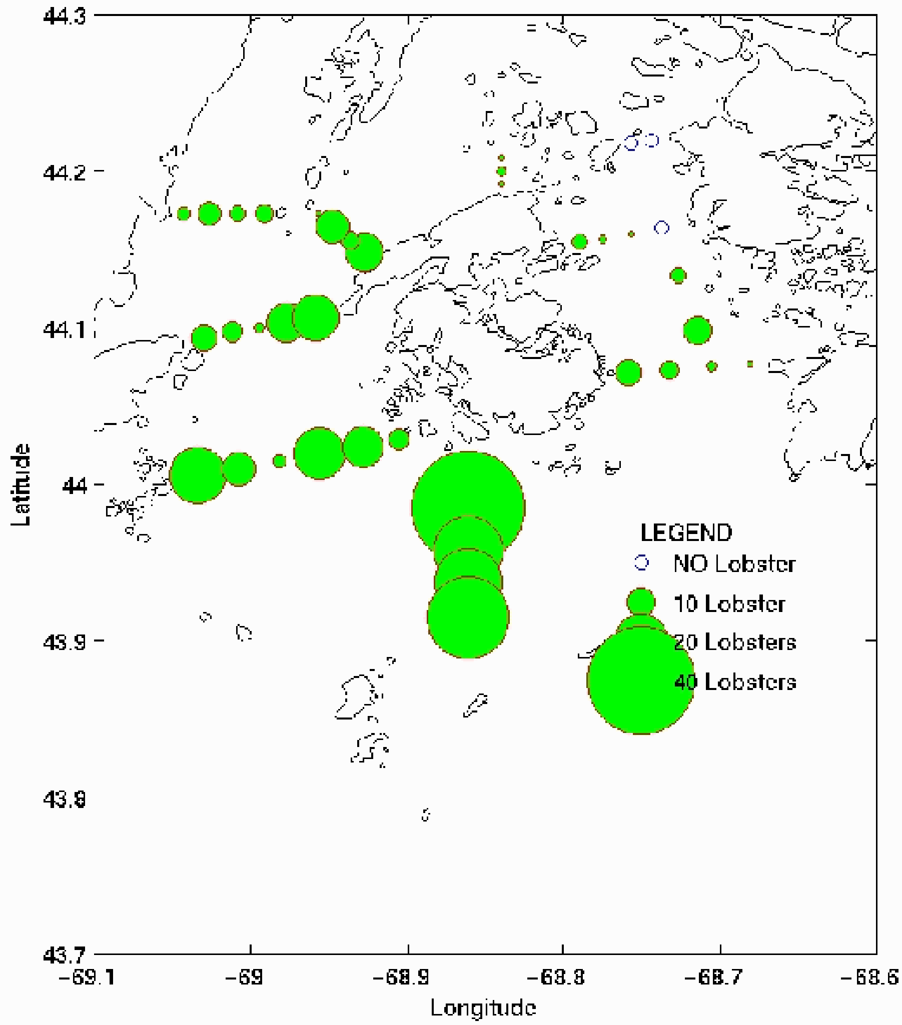

Fig. 3. Total number of lobster postlarvae collected at each sampling station during 1999. Stations from August 24 are not shown.

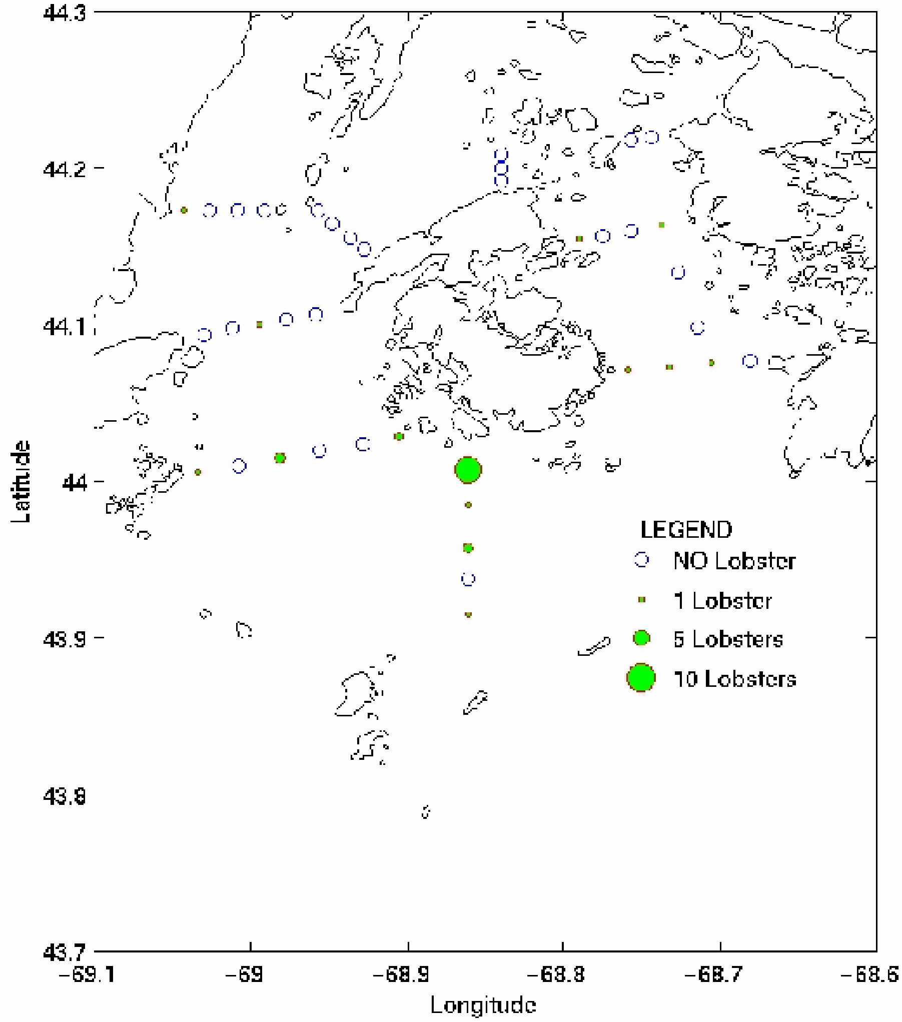

Fig. 4. Maximum concentration of larvae and postlarvae caught at the standard sampling stations (Fig. 1).

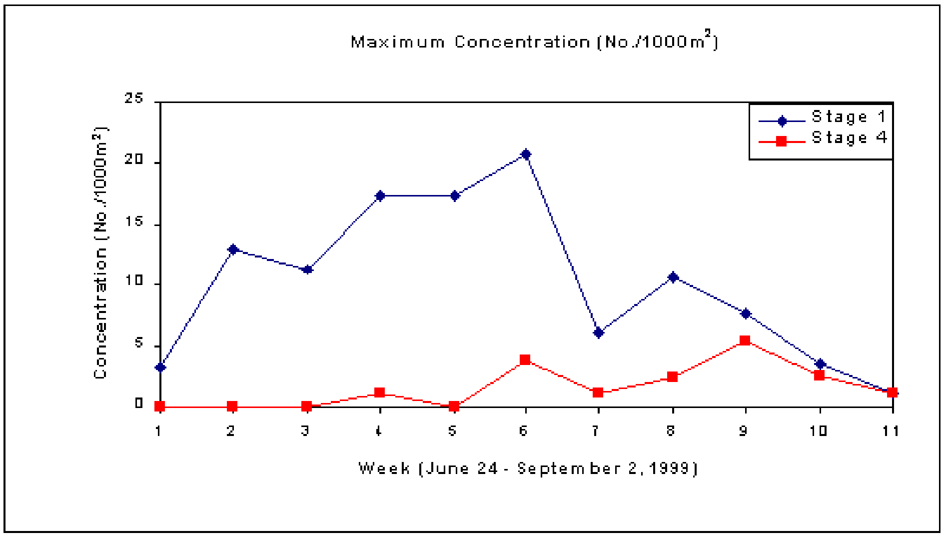

Fig. 5. Transect averages of sea surface temperature for each day of sampling in 1999. A missing line segment indicates no data for that day (*e.g.*, transect I, DOY 237 in bottom panel).

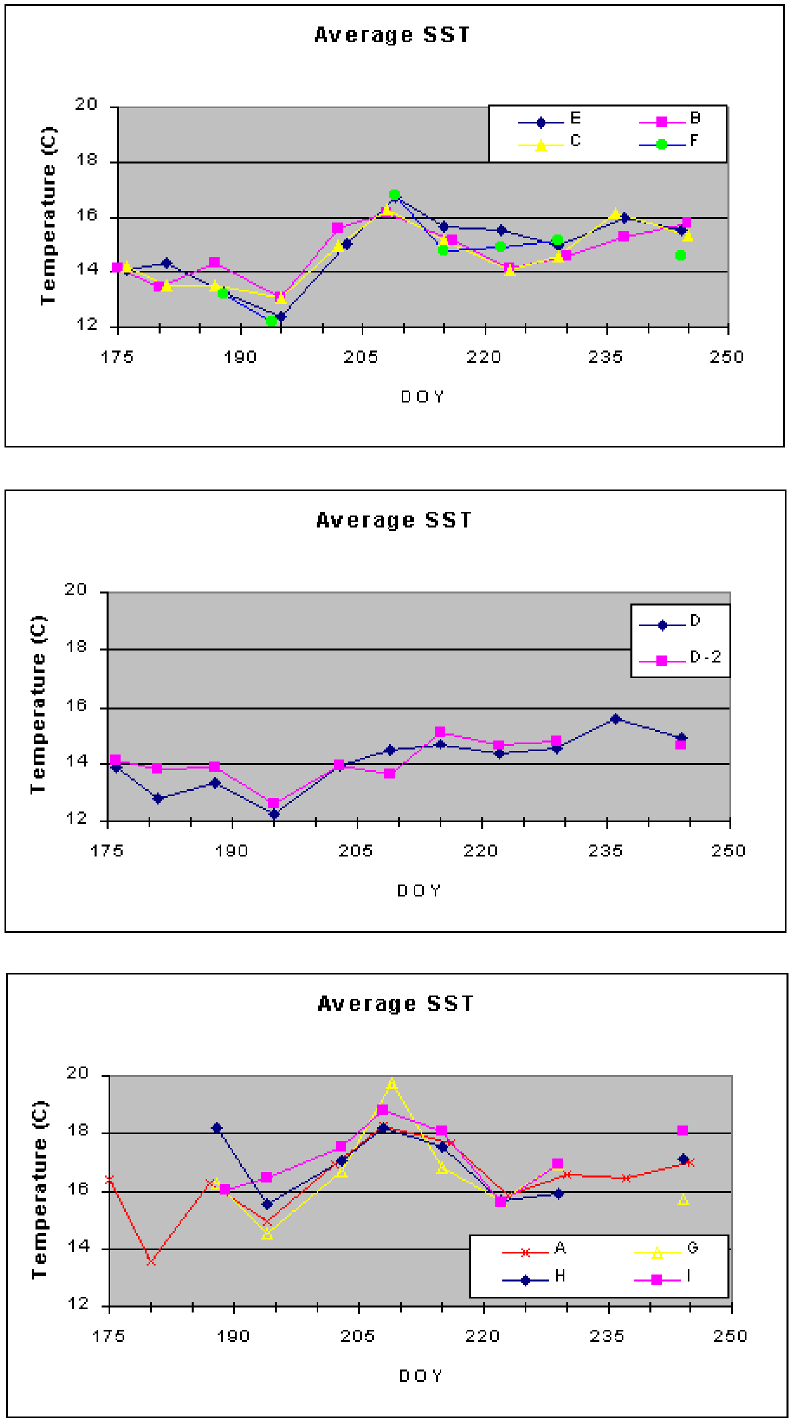

Fig. 6. As in Fig. 5, but for salinity at 2 m depth.